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FRANKFORD ARSENAL

WELDING 214, 356, AND ALMAG 35 CAST ALUMINUM ALLOYS TO 5456 WROUGHT ALUMINUM ALLOY

BY

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AMCMS Code 5026.11.84300
DA Project 1H024401A111

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ABSTRACT

Cast 214, 356-T6, and Almag 35 aluminum plate (3/8 in. thick) were welded to wrought 5456 aluminum alloy plate (3/8 in. thick), using the gas **tungsten**-arc process. Commercial filler metals 4043, 5183, and 5556 were used. Two beads were deposited on both sides of a double vee joint.

It was determined by radiography that the weldments were of excellent quality. No defects were noted, except for slight tungsten inclusions in one weld. All tensile test specimens, with the reinforcements removed, failed in the cast member with the following results.

Welded Combination Casting/Filler/Wrought	Approx Strength (psi) Yield	Tensile	Approx Joint Efficiencies[a] (%)
Almag 35/5183/5456 Almag 35/5556/5456	19,600	37,000	95
214/5183/5456 214/5556/5456	14,200	22,000	99
356-T6/5556/5456 356-T6/4043/5456	14,200	21,000	53

[a]Based on tensile strength of casting.

The weldments containing Almag 35 casting yielded the highest tensile properties. Although the joint efficiencies of the 356-T6/5456 weldments were low, the as-welded properties of this combination were approximately equal to the properties of the 214/5456 weldments. The choice of filler metals had little influence on the weldment properties.

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INTRODUCTION

Because of their relatively high strength-to-weight ratio, many aluminum alloys are being used in the manufacture of army equipment. In many of these items, wrought alloys, such as 2219, 2014, 5083, and 5456, are employed for structural integrity. The strain-hardenable 5000 series alloys, although of moderate strength in comparison with the 2000 and 7000 series heat-treatable alloys, are more weldable in many instances and are being used particularly in the construction of lightweight personnel carriers.

The incorporation of aluminum castings in an assembly is also often desirable from a design and production engineering standpoint. The difference in composition and structure between cast and wrought aluminum alloys, however, can present problems in joining. Although the need for joining cast to wrought components is becoming more prevalent, very little specific information has been reported on the weldability of such combinations.

In view of the need for this type of data, Frankford Arsenal investigated and reported the weldability of selected cast aluminum alloys to 5086 wrought aluminum sheet.[1] Alloy 5086 was of interest since it was being used extensively for missile applications. Of six casting alloys investigated, it was found that Almag 35, Al-7% Mg, and 214 could be satisfactorily welded to the 5086 material. Casting alloys of the 356 alloy family were not as weldable to 5086 because of the excessive formation of magnesium silicide.

Since the investigation relative to 5086 wrought aluminum sheet, two similar higher strength alloys (5083 and 5456) have come into prominence, particularly with the development of lightweight military vehicles, and a determination of their weldability with aluminum casting alloys was needed. Since both alloys are similar in composition and strength, it was believed that it would not be necessary to conduct duplicate experiments on each alloy and, therefore, an arbitrary decision was made to use 5456 alloy in this investigation. This report documents the work that ensued.

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[1]M. S. Orysh and I. G. Betz, "Study of the Weldability of Aluminum Casting Alloys with 5086 Wrought Aluminum Alloy," Frankford Arsenal Report R-1467, September 1958.

The casting alloys selected were 214, 356, and Almag 35. Almag 35 and 214 were chosen because of their weldability in the preceding study. Alloy 356, although less compatible with 5086, was also included since it is a leading high strength aluminum casting material and would probably be considered for many cast aluminum components.

MATERIALS

Wrought 5456 Aluminum Alloy Plate

Wrought 5456 aluminum alloy plates, 11-1/2 x 4-1/2 x 3/8 inches, were obtained by rolling 1-1/4 inch thick plate. The chemical composition of the plate is given in Table I. The mechanical properties (transverse to the rolling direction) of the rolled plate are given in Table II and the Appendix.

Cast Aluminum Alloy Plate

Alloys 214, 356, and Almag 35 were cast in the form of plate, 11-1/2 x 4-1/2 x 3/8 inches. The castings were made by the shell molding process from commercial ingot material. The 356 plates were heat treated to the T6 condition, using an air circulating furnace in which the solution treating and aging temperatures were controlled to within ±5° F. The chemical compositions of these alloys are also given in Table I.

Radiography indicated that the castings were sound. The mechanical properties of tensile specimens removed from the plates were within the requirements specified in Federal Specification QQ-A-601b, "Aluminum Alloy Sand Castings." These properties are also given in Table II and the Appendix.

Filler Metal

The filler metals selected for each cast-to-wrought combination are listed below. All were commercially available as welding electrodes.

TABLE I. Chemical Compositions of Base and Filler Metals

	Weight Percent							
	Mg	Si	Fe	Cu	Mn	Zn	Ti	Al
Wrought Metal:								
5456	5.53	0.15	0.21	0.08	0.64	0.03	0.02	Rem
Casting:								
Almag 35	6.41	0.11	0.11	<0.01	0.20	0.03	0.25	Rem
214	3.68	0.20	0.19	0.03	0.01	0.03	<0.01	Rem
356	0.26	6.94	0.13	<0.01	<0.01	0.01	0.11	Rem
Filler Metal:								
5556	5.25	<0.1	0.1	<0.05	0.79	N.D.	0.32	Rem
5183	4.79	<0.1	0.3	<0.01	0.6	<0.05	0.1	Rem
4043	<0.01	5.24	0.35	0.09	<0.01	<0.05	<0.01	Rem

TABLE II. Tensile Data of Base Metals and Their Welded Combinations

	Ultimate Tensile Strength (psi)				Yield Strength (psi)[a]				Percent Elongation[b]			
	Max	Min	Avg[c]	σ[d]	Max	Min	Avg[c]	σ[d]	Max	Min	Avg[c]	σ[d]
Wrought Alloy, Unwelded												
5456	59,200	58,300	58,800	400	45,700	44,400	45,300	500	10.4	9.4	9.8	0.4
Cast Alloys Unwelded												
Almag 35	42,300	37,000	39,200	2700	20,000	19,200	19,600	300	18.8	9.5	13.5	4.1
214	24,200	20,300	22,100	1600	13,600	12,700	13,100	300	7.2	4.4	5.7	1.3
356-T6	41,400	37,800	39,900	1400	34,900	32,500	34,400	1000	3.0	2.0	2.3	0.4
Weldments (Casting/Filler/Wrought)												
Almag 35/5556/5456	37,600	36,600	37,100	400	19,900	19,000	19,600	400	11.5	9.6	10.8	0.9
Almag 35/5183/5456	39,300	35,100	37,400	1700	20,000	19,000	19,600	400	12.5	8.7	11.2	1 8
214/5556/5456	22,500	21,500	22,100	400	15,300	14,100	14,500	500	5.0	3.7	4.6	0.5
214/5183/5456	22,200	20,900	21,600	600	14,100	13,600	13,900	200	4.8	4.2	4.5	0.3
356-T6/5556/5456	20,800	20,300	20,600	200	14,300	13,200	13,500	400	6.6	5.6	6.2	0.4
356-T6/4043/5456	21,400	20,900	21,200	200	15,200	13,900	14,400	500	6.4	5.8	6.2	0.2

Notes:

a - 0.2 percent offset
b - In 2 inch gage length
c - Average of 5 specimens
d - Estimated Standard Deviation

Casting	Filler Metal	Wrought Plate
Almag 35	5183, 5556	5456
214	5183, 5556	
356-T6	4043, 5556	

Alloy 5556 was developed by industry for welding 5456 and was an obvious choice for this investigation. Its chemical composition is essentially the same as that of 5456 except that the maximum limit on copper is lower, thus maintaining corrosion resistance in the cast deposit. Titanium, which is intentionally added to 5556, serves as a grain refiner.

Alloy 5183, on the other hand, was originally developed for welding 5083, but has also become recognized and accepted as an effective filler metal for fabricating the 5456 alloy. In this investigation, 5183 was considered a particularly promising filler for the 214/5456 combination since its magnesium content, unlike that of 5556, was between the magnesium compositions of both base metals.

Filler metal 4043 was investigated only in connection with the 356/5456 combination, which presented the greatest chemical dissimilarity. From the previous work,[1] it was expected that the joining of these two alloys would present the greatest weldability problem of the three combinations under investigation. In this instance, filler metals 4043 and 5556 favored the cast and the wrought members, respectively, with regard to silicon and magnesium contents.

WELDING PROCESS AND EQUIPMENT

All welding was manually performed, using the gas tungsten-arc process. The equipment consisted of a 230/460 volt, 60 cycle ac-dc arc welder, with a high frequency arc initiation control. A wave balancer was also used in conjunction with the welder to minimize the dc component and give equal wave halves for secondary ac current operation.

[1] Ibid.

PROCEDURE

The study was limited to the preparation and testing of weldments having base members (both cast and wrought) of equal thickness. It was anticipated that failure under tension would occur either in the weld or the casting, in view of possible embrittlement in the weld due to dilution with base metal products and the relatively weak structure of the weld and castings with respect to the 5456 member. The wrought alloy (5456) is generally recognized as being readily weldable, at least when 5556 or 5183 filler metal is used. Although weldments could have been designed to force failure in the vicinity of the wrought member, such an approach was not undertaken in this project.

Joint Preparation

The joint geometry consisted of a 90° double vee groove, having a 1/16 inch root face and no root opening. This geometry was consistent with generally accepted welding practice for 3/8 inch thick plate.

The plate surfaces to be welded (11-1/2 inch side of plates) and the adjacent surfaces for a distance of one inch from the joint were cleaned prior to welding.

The wrought 5456 plates were cleaned by immersion in a solution of nitric-hydrofluroic acid for four minutes. The acid solution consisted of 3.8 liters of water to which were added 0.4 liter of technical nitric acid (58% to 62% HNO_3) and 0.03 liter of technical hydrofluoric acid (48% HF). After immersion, the plates were washed with cold water and dried using compressed air.

The castings were cleaned by sanding the bevelled surfaces and adjacent areas. The castings were then wiped with alcohol and air dried to circumvent possible moisture entrapment in surface irregularities that are normally characteristic of castings.

Welding

One cast and one wrought plate for each alloy combination listed under "Materials" were joined. The welds were made along the longer side of the pieces, transverse to the rolling direction of the wrought plate.

Welding was accomplished by depositing two weld beads on each side of the joint. The welding data, except for voltage, are listed in Table III. Available methods of measuring such voltage could not be used due to the high frequency pilot circuit of the welding machine.

TABLE III. Welding Data

Welding voltage	(v)	NM[a]
Welding current, ac	(amp)	190 to 200
Argon shielding gas flow	(liters/min)	12 to 15
Tungsten electrode diameter	(in.)	3/16
Filler rod diameter	(in.)	3/32
Prewelding temperature of fixture	(°F)	100 to 120
Number of passes		4

[a]NM - Not measured.

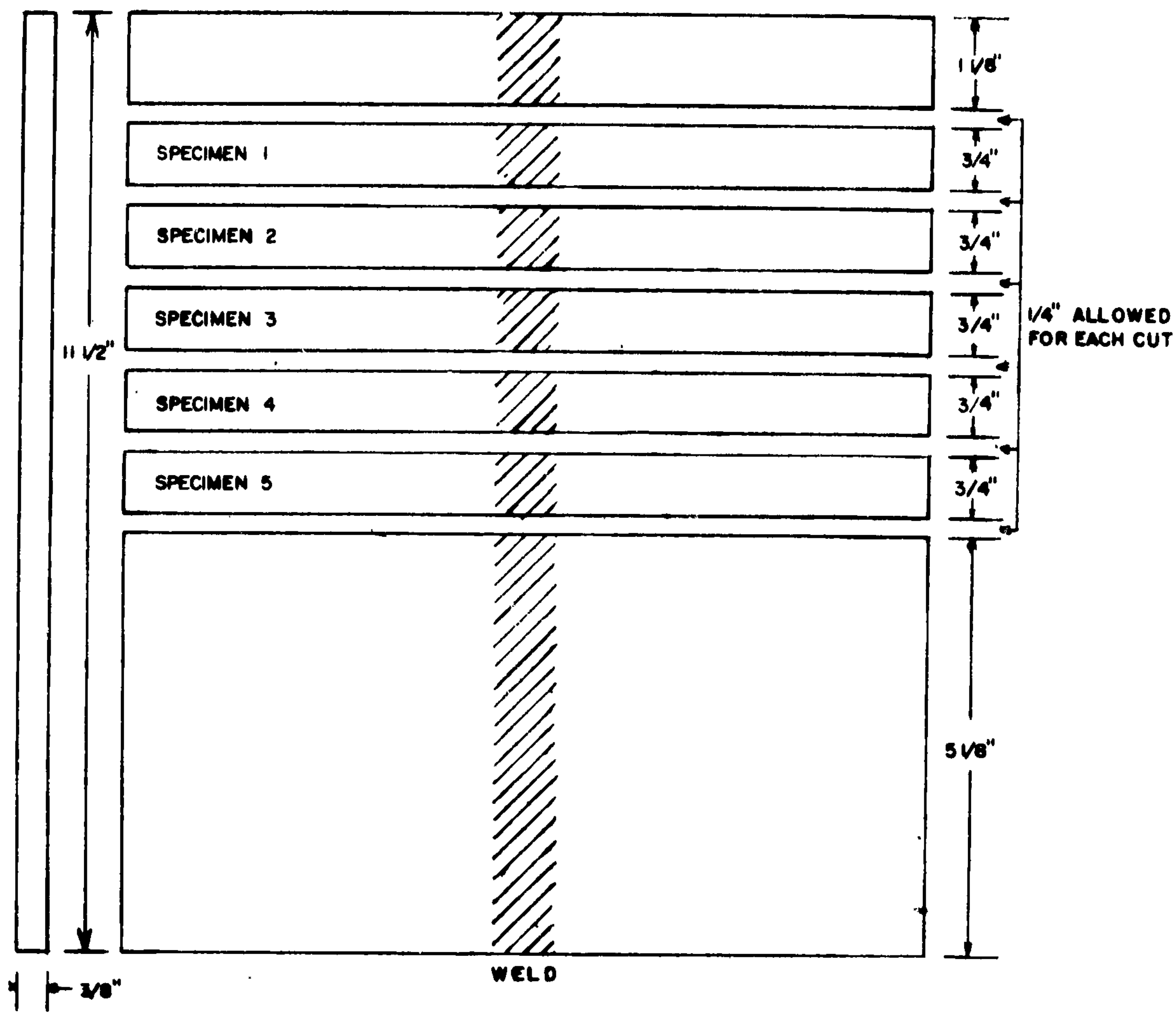
Preparation and Testing of Tensile Specimens

Both faces of all weldments were fully machined, removing 1/16 inch from each side. Thus, the reinforcement was removed and the thickness of the weldments was reduced from 3/8 to 1/4 inch. Five transverse weld specimens were then cut from each weldment, as shown in Figure 1, and machined into standard tensile test specimens.[2] Tensile specimens were also removed from unwelded cast and wrought material in order to obtain comparative data.

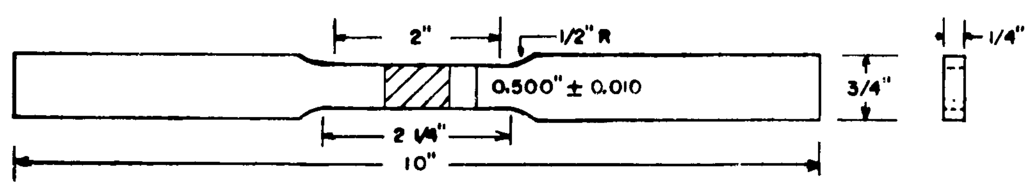
All welded specimens were radiographed to establish the quality of the weld. The radiographs were evaluated by comparison with Purchase Description ABMA-PD-B-27 "Radiographic Inspection; Soundness Requirements for Fusion Welds in Aluminum and Magnesium Missile Components."

The specimens were then tested in a 20,000-pound capacity hydraulic tensile testing machine, using a cross head travel speed of

[2]"Federal Test Method Standard No. 151," Specimen F2, Figure 3, 17 July 1956.



A - Sectioned Weldments



B - Transverse Weld Tensile Test Specimen

Figure 1. Location and dimensions of Tensile Specimens

approximately 0.05 in./min. The yield strength of each specimen was determined at 0.2 percent offset. The ductility of the specimens was determined in terms of percent elongation in a 2-inch gage length.

RESULTS AND DISCUSSION

Radiographic Examination

With the exception of two specimens, no defects were noted in any of the welds. The two specimens, machined from the 356/4043/5456 (casting/filler/wrought) weldment, contained small scattered tungsten inclusions in the weld deposit. In accordance with the Purchase Description, the tungsten particles were regarded as a form of scattered porosity and, on this basis, the specimens were comparable to Reference Radiograph A1-2, and would be considered "borderline," but would not be considered rejectable quality unless other "borderline" defects existed.

All specimens, except the previously mentioned two, would be considered "acceptable" under the most rigid quality assurance requirements, - Class I of the Purchase Description. These two specimens, however, would be "acceptable" under Class II, the second of five classifications for soundness and quality. All welds, therefore, were "acceptable" at the level of at least Class II of the Purchase Description.

Tensile Tests

The average transverse tensile properties of each welded combination are graphically presented in Figure 2 and listed in Table II along with their corresponding standard deviations. The tensile properties of individual specimens are given in the Appendix.

All tensile specimens failed through the cast base member at approximately 1/4 to 1/2 inch from the fusion line. In terms of joint efficiencies, both the Almag 35/5456 and 214/5456 combinations produced the highest results, as shown in the following tabulation.

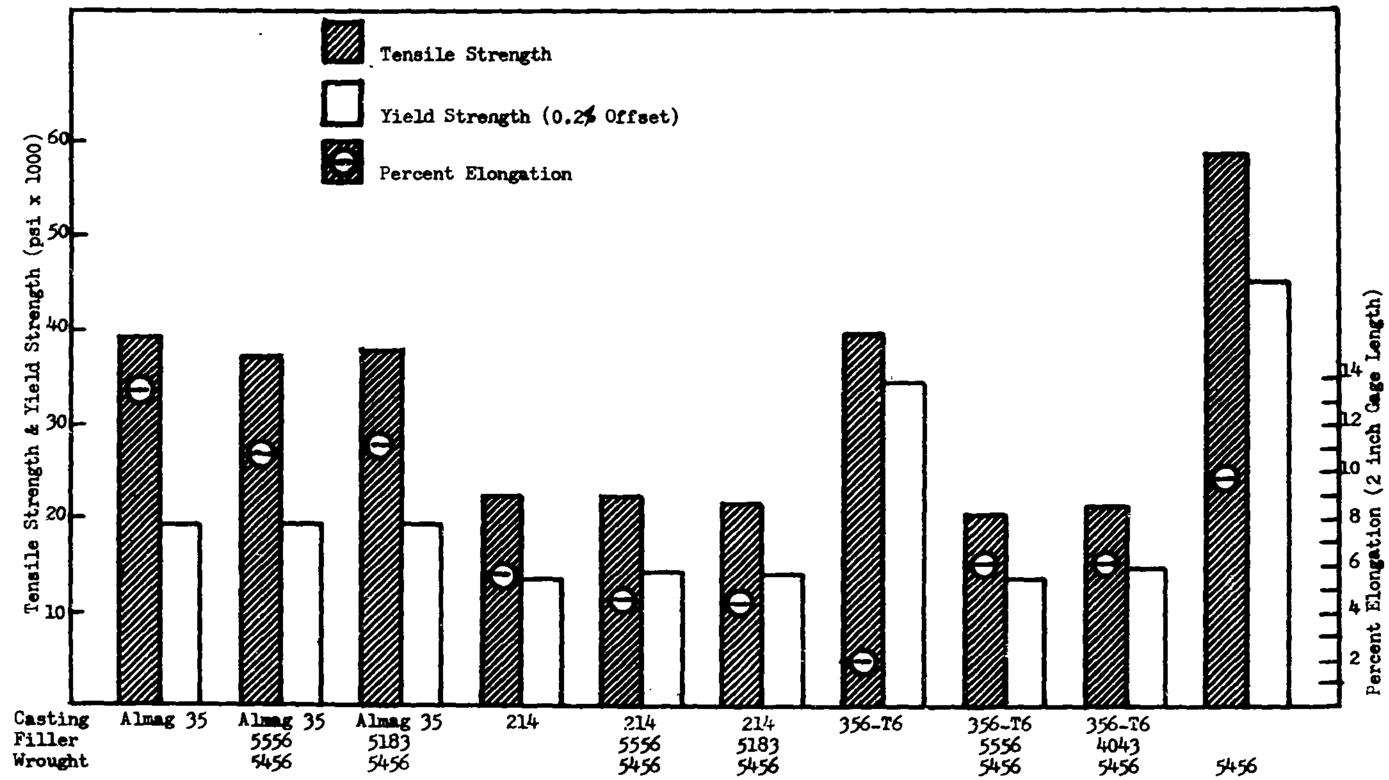


Figure 2. Average Tensile Properties of Base Metals and their Welded Combinations

Welded Combination (Casting/Filler/Wrought)	Average Joint Efficiency* (%)
Almag 35/5556/5456	95
Almag 35/5183/5456	95
214/5556/5456	100
214/5183/5456	98
356-T6/5556/5456	52
356-T6/4043/5456	53

*Based on tensile strength of unwelded casting

These efficiencies are similar to those obtained in previous work wherein the above castings were welded to 5086 wrought aluminum alloy.[1] Although the calculated average efficiencies for the Almag 35/5456 combinations were both 95 percent, statistical treatment of the tensile data produced no significant difference between the strengths of the unwelded Almag 35 casting and those of the weldments. As expected, the joint efficiencies of the 356-T6/5456 combinations were low. The deterioration in properties was the direct result of the heat of welding on the heat-treated cast structure. No effort was made to test weldments heat treated after welding, although an improvement would be expected. Often the heat treating of fabricated structures is difficult, if not impossible, and so performance must depend on the as-welded properties of the item.

Considering the tensile data, the Almag 35/5456 weldments, without exception, provided the highest properties. The ultimate tensile strengths obtained were nearly 70 percent higher than the other two combinations. Yield strengths were over 30 percent greater, and percent elongations exceeded the other combinations by at least 75 percent. These differences, when comparing 214 with Almag 35, are a reflection of the differences in properties of the unwelded castings. As previously noted, however, the lower strengths experienced with the 356 alloys were caused by the welding operation.

[1] Ibid.

It was also noted that the properties of the 356/5456 weldments were essentially the same as those obtained with 214/5456 combinations, although a significant deterioration occurred in the 356 alloy as a result of welding.

This work indicated, therefore, that Almag 35 is the most desirable casting of the three for use with 5456. Also, there appears to be little advantage in selecting 214 in preference to the 356-T6 alloy in so far as weldment tensile properties are concerned, even though a 100 percent joint efficiency is obtainable with the 214 casting.

The filler metals used to weld different base metal combinations apparently had little effect on the properties of the weldments or their fracture location. Only weldments of combinations 356/4043/5456 and 356/5556/5456 showed any difference in their results. Welded specimens made with filler metal 4043 were slightly higher in yield and ultimate tensile strengths than were those made with 5556. Although it is believed unlikely that the filler metals contributed to this slight difference, the significance, if any, of this variation could not be determined in this study.

The ability of filler metals to exert an influence on the mechanical properties of these weldments could depend on the dimensional features of the joint. Assuming that the filler metal influence would be reflected principally within the weld metal, the effect could become distinguishable and significant if some other joint design were employed in the test specimens. As an example, an increase in casting thickness with respect to other sections of the joint might cause the weld to become the most critical area, subject to failure. Under these conditions, the filler metals might have a more pronounced effect on the performance of the weldment.

CONCLUSIONS

1. The 214 and Almag 35 castings were successfully welded to 5456 wrought aluminum alloy, using either 5183 or 5556 filler metals and the gas tungsten-arc welding process. The quality of these weldments was excellent in that no defects were noted except for slight scattered tungsten inclusions in one weld.

2. The welded Almag 35/5183/5456 and Almag 35/5556/5456 (casting/filler/wrought) combinations failed at approximately 37,000 psi, with an average joint efficiency of 95 percent based on the original tensile strength of the casting.

3. The welded 214/5183/5456 and 214/5556/5456 combinations failed at approximately 22,000 psi, with an approximate joint efficiency of 99 percent based on the original strength of the casting.

4. The welded 356-T6/5556/5456 and 356-T6/4043/5456 combinations failed at approximately 21,000 psi, with an approximate joint efficiency of 53 percent.

5. Welds made between casting alloy 356-T6 and wrought 5456 alloy were of high quality but, in the as-welded condition, weldments failed at strengths significantly below the original strength of the casting due to over-aging of the heat-treated casting by welding.

6. All tension test specimens with reinforcement removed failed in the cast member of the joints since both members were of equal thickness.

7. The filler metals used in this investigation apparently had little influence on the tensile results of the three base metal combinations when welded in this configuration.

APPENDIX

TENSILE DATA

Tensile Properties of Cast and Wrought Aluminum Alloys

Alloys		Strength (psi) Ult Tensile	Strength (psi) Yield[a]	Elongation[b] (%)
Almag 35		37,000	19,300	10.4
		38,000	19,200	12.0
		42,100	19,700	18.8
		42,300	20,000	16.8
		36,800	19,600	9.5
	Avg	39,200	19,600	13.5
214		20,300	12,900	4.4
		24,200	13,200	7.0
		23,200	13,600	7.2
		21,300	12,700	4.9
		21,400	13,100	5.4
	Avg	22,100	13,100	5.7
356-T6		37,800	32,500	2.0
		39,500	34,600	2.0
		40,700	34,900	2.5
		41,400	33,600	3.0
		40,300	34,600	2.0
	Avg	39,900	34,000	2.3
5456		58,600	44,400	9.6
		59,200	45,500	9.8
		59,200	45,700	10.4
		58,800	45,700	9.9
		58,300	45,400	9.4
	Avg	58,800	45,300	9.8

[a]At 0.2 percent offset

[b]In 2-inch gage length

Transverse Tensile Properties of Cast Aluminum Alloys Welded to 5456 Wrought Alloy

Material Combinations (Cast/Filler/Wrought)	Strength (psi) Ult Tensile	Strength (psi) Yield[a]	Elongation[b] (%)
Almag 35/5556/5456	37,100	19,900	c
	37,300	19,800	11.4
	37,600	19,000	11.5
	37,000	19,400	10.7
	36,600	19,900	9.6
Avg	37,100	19,600	10.8
Almag 35/5183/5456	38,600	19,600	12.4
	39,300	19,700	12.5
	38,000	20,000	12.4
	36,200	19,000	10.0
	35,100	19,500	8.7
Avg	37,400	19,600	11.2
214/5556/5456	22,400	15,300	3.7
	21,800	14,400	4.8
	21,500	14,400	4.6
	22,500	14,100	5.0
	22,400	14,600	4.8
Avg	22,100	14,500	4.6
214/5183/5456	20,900	14,100	4.2
	21,300	13,800	4.2
	22,200	13,600	4.8
	21,700	13,900	4.4
	22,100	13,900	4.8
Avg	21,600	13,900	4.5
356-T6/5556/5456	20,400	13,400	6.3
	20,300	13,500	5.6
	20,700	13,200	5.9
	20,600	13,300	6.6
	20,800	14,300	6.6
Avg	20,600	13,500	6.2

[a]At 0.2 percent offset

[b]In 2 inch gage length

[c]Broke outside of gage marks

Transverse Tensile Properties of Cast Aluminum Alloys
Welded to 5456 Wrought Alloy (Cont'd)

Material Combinations (Cast/Filler/Wrought)	Strength (psi) Ult Tensile	Yield[a]	Elongation[b] (%)
356-T6/4043/5456	21,100	14,100	6.4
	20,900	14,200	6.1
	21,200	13,900	6.2
	21,400	14,500	5.8
	21,400	15,200	6.3
Avg	21,200	14,400	6.2

[a]At 0.2 percent offset

[b]In 2 inch gage length

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WELDING 214, 356, AND ALMAG 35 CAST ALUMINUM ALLOYS TO 5456 WROUGHT ALUMINUM ALLOY by M.S.Orysh and I.G.Betz

FA Rpt R-1726, Jul 64; 20 pp incl tables and illus.
AMCMS Code 5026.11.84300; DA Project 1H024401A111
Unclassified Report

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It was determined by radiography that the weldments were of excellent quality. No defects were noted, except for slight tungsten inclusions in one weld. All tensile test specimens, with the reinforcements removed, failed in the case member.

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2. Joining of Dissimilar Metals
3. Arc-welding
4. Casting
5. Aluminum
6. Mechanical Properties

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II. M. S. Orysh
I. G. Betz
III. AMCMS 5026.11.84300
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